Layered Organization in the Coastal Ocean: Acoustical Data Acquisition, Analyses and Synthesis

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LONG-TERM GOALS

The long-term goal of our research is to improve our ability to observe the ocean's plants, animals, and their physical and chemical environment at the scales that control how they live, reproduce, and die.

OBJECTIVES

In August and September 2005 we collected acoustical volume scattering and ancillary environmental data in the northeastern corner of Monterey Bay, CA. The effort was a part of a multi-investigator ONR field experiment titled “Layered Organization in the Coastal Ocean” (LOCO). The effort in 2005 (LOCO 2005) was followed in July 2006 by a second occupation of the same shallow, shelf area in Monterey Bay (LOCO 2006). Our highest priority during both experiments was to support our colleagues in the larger LOCO effort with timely data regarding the zooplankton and micronekton response to the physical and biological (food, predators and prey) fields at a carefully selected process study site. We used a suite of environmental and acoustical sensors to do this, with data being transmitted from an array of sensors offshore via real-time telemetry to our shore-station, followed by distribution to the LOCO group by e-mail, meetings, telemetry to participating ships, and a project web site for use by LOCO participants. For our own basic research focus, we utilized sensors designed detect the presence, distribution and numbers of zooplankters, micronekton and small gas bubbles that might be associated with thin phytoplankton layers. Our work during FY 2006 was divided between analyzing data from the first experiment and preparing for the second field period.

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APPROACH

A growing body of evidence suggests that several kinds of fine-scale vertical structures (10's of cm to a few meters) are ecologically important; however, there are still new things to learn about the mechanisms involved in their formation, dissipation, and utilization by different trophic assemblages. For the last few years we have been collaborating closely with other ONR-sponsored researchers in a project that is focused on thin physical, biological and chemical structures. With the larger LOCO group we are uncovering details of how fine-scale vertical distributions of organisms such as protists, phytoplankton, zooplankton, micronekton and fish interact, eventually impacting both higher and lower trophic levels in the food web. We are also attempting to better observe other processes that could affect ocean optics, acoustics, and small-scale physics and chemistry, e.g., the creation of small gas bubbles in thin phytoplankton layers and in the top few cm of the seabed.

In 2002, along with our colleagues from the University of Rhode Island and the University of California, Santa Cruz, we conducted quick surveys of several shallow water coastal locations on the Atlantic, Pacific and Gulf of Mexico coasts of the United States. The objective was to find a good location for a dedicated experiment to study the dynamics of thin plankton layers and their characteristics. During the fall of 2005, very thin layers of phytoplankton, zooplankton, nutrients, and physical structure were studied by a part of the LOCO research team at stations near the 20 m contour in northern Monterey Bay. Other team members examined larger scale horizontal distributions and temporal patterns in deeper water nearby. A follow-on field experiment near the same location in Monterey Bay was conducted during July 2006.

WORK COMPLETED

All of the data from the 2002 "Quicklook" exercise has been examined in detail, however it has not been fully compared to data sets collected subsequently. Only about 4% of the LOCO 2005 and LOCO 2006 data have been analyzed in detail. Some of the LOCO 2005 analyses were presented at a special session on the oceanography and ecology of thin plankton layers at the Ocean Sciences meeting in Honolulu in February 2006. A significant amount of our LOCO resources during the first half of FY06 have been dedicated to preparations for the LOCO 2006 experiments. Our activities have also included participation in the deliberations of the LOCO scientific steering committee, responding to requests for information needed to obtain the necessary environmental permits to operate in the Monterey Bay National Marine Sanctuary, and making arrangements for the program's small boat support. Our field work is now completed and analysis efforts have resumed.

RESULTS

Our "Quicklook" at the northeastern corner of Monterey Bay covered the period from August 6 through September 9, 2002. Thin zooplankton layers were in evidence throughout most of the period, although overall zooplankton abundances were not as high as have been observed at other coastal locations. A 700 kHz record of volume scattering strength illustrates the vertical pattern for acoustical scattering during a typical 24-hr period (Fig. 1). The record was made with a multi-frequency up-looking TAPS-6 zooplankton sensor mounted on a frame placed on the seabed. Telemetry to a shore station just south of Aptos, CA provided real-time data access and sensor control. When the data in Fig. 1 were combined with simultaneous volume scattering strength records from the other frequencies, we performed calculations to reveal the size-biomass spectra for the time and depth interval in the small "box" outlined in black at *ca*. 19 hr in the top panel. The biomass is expressed as the $\log_{10}$ of the effective displacement volume (BV) for the zooplankters present in a cubic meter of seawater. Those results are shown for two generic zooplankton shapes in the two lower panels of Fig. 1. The "fluid sphere" shape is an acoustical estimate of the size-abundance spectrum for quasi-spherical shaped organisms, e.g., copepods, ostracods, or eggs. The "elongate" size-abundance spectrum is for organisms with shapes similar to a euphausiid or a mysid.

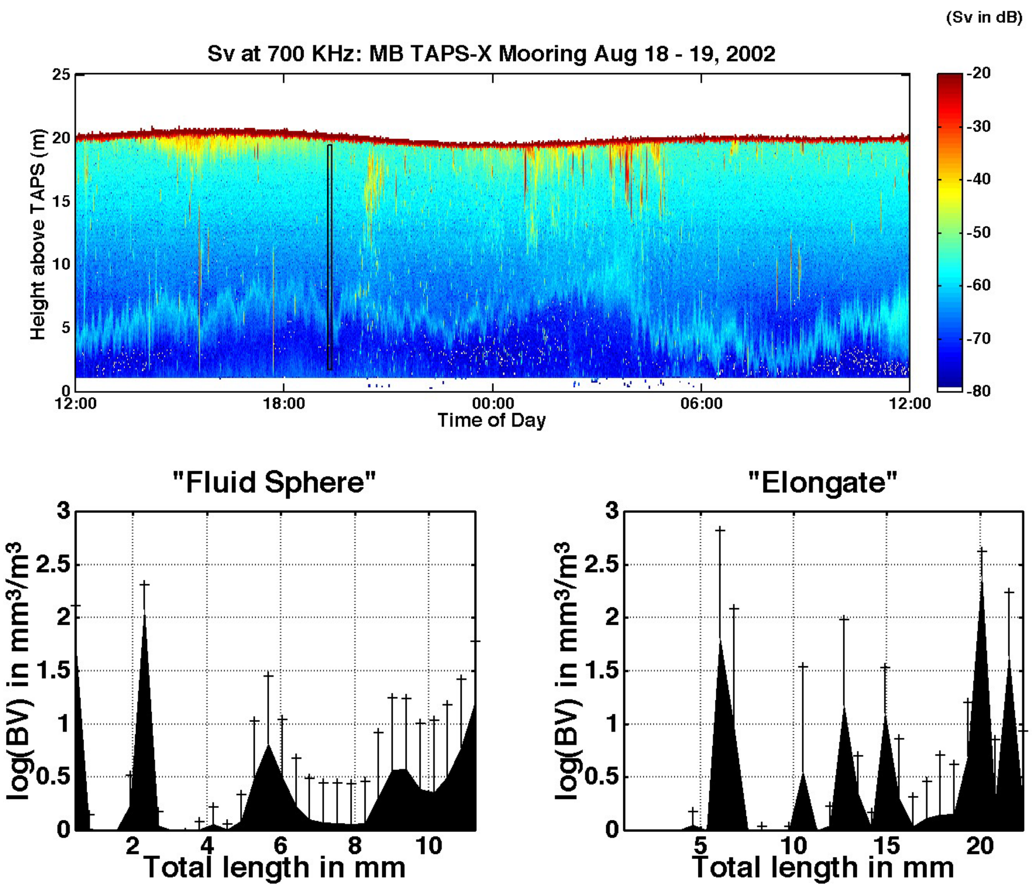

Figure 1: A 24-hr long TAPS-6 acoustical sensor record illustrates a thin scattering layer recorded in August 2002. The thin layer varies from near the seabed to heights of about 10 m off the bottom in 20 m of water. Layer thicknesses were less than a meter most of the time, but occasionally thickened to a few meters. The thin layer was modulated in depth by small internal waves. The average size-abundance spectra for two generic organism shapes are shown in the bottom two panels for a few minutes at about 1900. Quasi-spherical scatterers, e.g., copepods, ostracods and eggs, were detected at sizes of ca. 100 μm, 2.2 mm. The biovolume (BV) for the most abundant copepod-like scatterer was only 100 mm^3 / m^3. Lesser abundances were found at discrete larger sizes. Elongate organisms, e.g., with shrimp-like shapes, were found at lengths of ca. 6, 10.1, 12.6, 15, 20 and 21.5 mm. The 21.5 mm long elongate scatterers were the most abundant organisms in the thin layer (ca. 100 mm^3 / m^3).

In the fall of 2005 the "Quicklook" site was occupied again. A 24-hr TAPS-6 record of volume scattering strengths collected at 2 min intervals revealed the presence of a weak thin layer that varied from *ca*. 8 m above the seabed at noon to as close as 2 m at midnight and then back to *ca*. 8 m the next morning (Fig. 2). In that layer, 16 mm elongate scatterers (mysids) numerically outnumbered 2 mm quasi-spherical scatterers (copepods) by 2.5:1. In 2005 daytime thin layers of this type were rare, more diffuse and patchier than in 2002. *Acartia tonsa* resided in the top 1 m of the water column during the day (confirmed with pumps and nets). At dusk organisms that had been just under the surface migrated to depths where Donaghay and Rines (GSO/URI) determined there were thin diatom layers. On some evenings, vertical migrators from near or in the seabed joined them in mid-water. The migrating assemblages of zooplankton and micronekton usually returned to their original depths well before dawn. There was no discernable zooplankton or micronekton response to a migrating thin dinoflagellate layer. Two distinct layers can be seen in midwater between dusk and about 0300 at night. Multi-frequency inverse calculations at the time marked by the black box revealed that the deeper of the two thin zooplankton layers contained organisms consistent in size and shape with the migrating *Acartia tonsa* (2 mm length), while both layers contained 16 mm elongate organisms consistent in size with mysids collected in the area during the experiment.

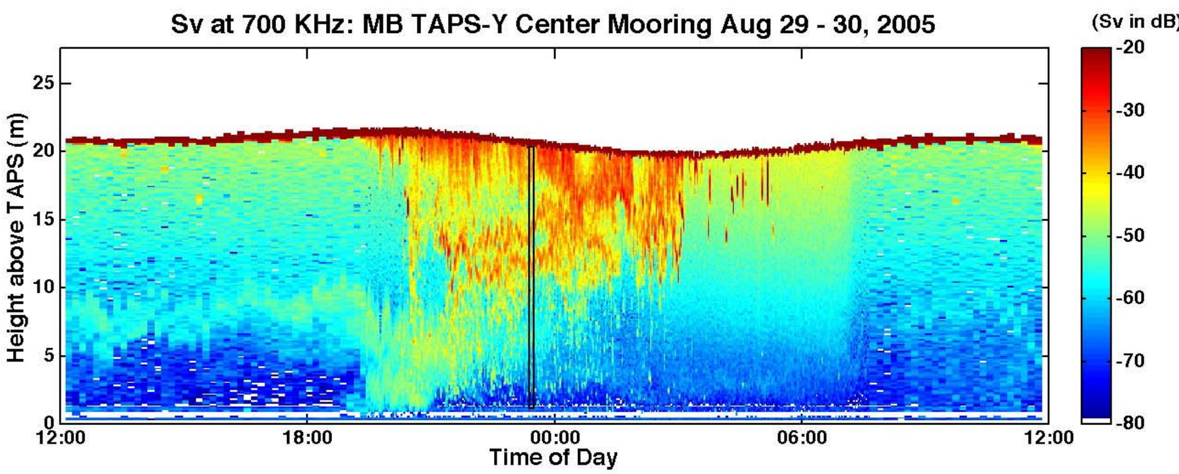

Figure 2: A 24-hr TAPS-6 record at 700 kHz reveals that the principal zooplankton response observed during LOCO 2005 was at night when organisms migrated from the surface and near or in the seabed to mid-water and formed one or more thin layers. At, and after dusk, the surface population completely ignored a migrating thin dinoflagellate layer and migrated to depths where Percy Donaghay's LOCO team found thin layers of diatoms. As on the day shown here, the zooplankton usually returned to within ca. 1 m of the surface well before sunrise.

Zooplankton distributions observed during LOCO 2006 were similar to those seen in Monterey Bay during 2002 and 2005. A typical vertical paterrn for the vertical distribution of volume scattering at 700 kHz is shown in Fig. 3. Thin layers reminescent of 2002 were observed at the start of the experiment (July 11). Daytime zooplankton thin layers were rarely observed after the first few days, after which only weak night time migrations dominated the scattering patterns. There is evidence that the water column was replaced through advection at the time the thin mid-water layers disappeared.

On August 18-19, 2006 a two layer pattern developed as a result of vertical migration at dusk, ending well before dawn (Fig. 3). The layer at *ca*. 3 m depth was dominated by two sizes (16 and 21.5 mm) of elongate scatterers that may have been mysids or euphausiids. The shallow layer, which will be subjected to more detailed analysis, was near, if not coincident with, a very thin layer of phytoplankton, largely *Alexandrium catenella* and *Dinophysis fortii* (J. Rines, pers. comm). The chl-a values at 1800 and 2100 hr were 23 µg/l and 20 µg/l respectively. *A. catenella* is potentially the source of a paralytic toxin and *D. fortii* has been associated with diarrhetic shellfish poisoning. The scattering from the layer at *ca*. 10 m depth was consistent with an assortment of 2 mm copepods, a low biomass of 10 mm amphipods and a few 16 mm mysids or euphausiids. The phytoplankton in the mid-water layer included an assemblage of diatoms and the dinoflagellate *Ceratium* spp. Chl-a values in that layer were 10 µg/l at 2200 hr (data on the phytoplankters from Percy Donaghay, Jim Sullivan and Jan Rines, at GSO/URI). Although present with an order of magnitude less biomass than the krill-shaped organisms, acoustical signatures suggest that a few amphipods may also have been in the layer at 10 m.

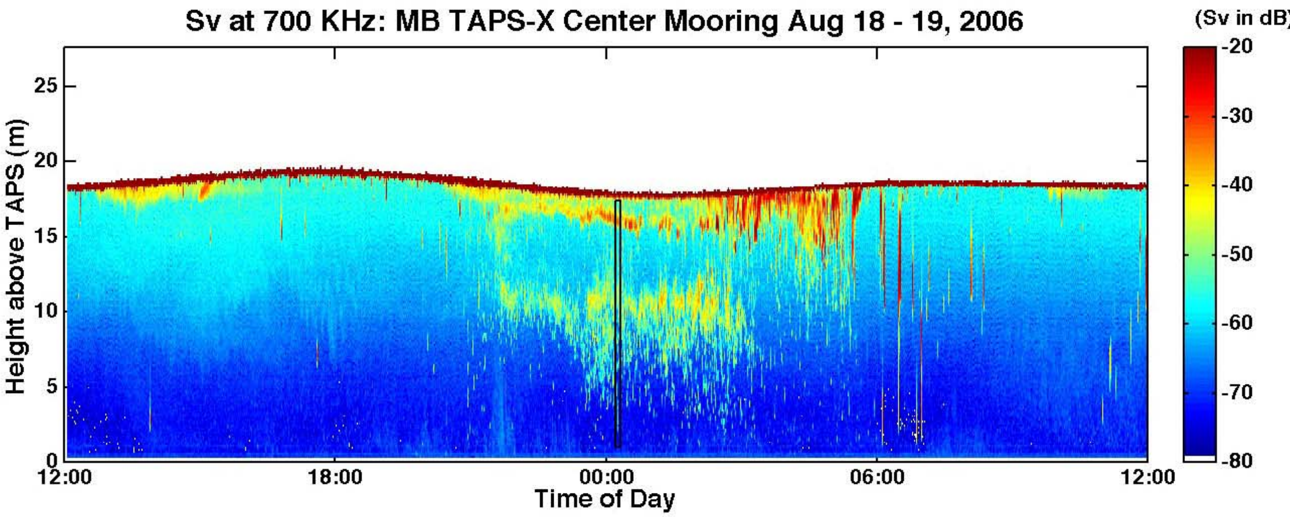

Figure 3: Measurements of volume scattering strength profiles once each minute for a 24-hr period at a station in NE Monterey Bay, CA reveals minimal or no layered structure in 700 kHz scattering during the day. Two thin layers ca. 1 m thick formed as a result of vertical migration during the night. In the interval marked by the "box" (just after midnight), the scattering in the top layer was consistent with the presence of mysids or euphausiids at 16 and 21.5 mm lengths. The mid-water layer scattering was consistent with the presence of 2 mm copepods and low numbers of 12 mm organisms (possibly amphipods) and 16 mm elongate scatterers, i.e., euphausiids or mysids. The mid-water layer was patchy and modulated in depth by small internal waves.

IMPACT/APPLICATIONS

Taken together, the data collected during 2002, 2005 and 2006 in Monterey Bay strongly suggest that fine-scale vertical structures and diel vertical migrations are ecologically significant in the plankton. The mechanisms involved in thin layer formation and the utilization of those layers by different trophic assemblages are much better described than when we started our research. It is our hope that when these findings are examined in the light of the different data sets (e.g., phytoplankton and chl-a profiles, plankton species, small scale physical oceanography, etc.) collected by our co-principal investigators in LOCO, numerous critical questions about the coastal ecosystem can be addressed by the LOCO teams. The LOCO data sets are truly unique, with several components resulting from sampling that was specifically directed to observed phenomena as a result of having real-time data from the TAPS and ORCAS variants that were deployed by ourselves and the URI team. The distribution of marine life at all trophic levels impacts current and future naval systems, especially those used in shallow water, where both mine detection and ASW operations must be conducted prior to engaging in expeditionary warfare. Additionally, the phenomena we are addressing can impact the battlespace environment in several ways and should be characterized and considered in planning for special forces operations.

TRANSITIONS

We have successfully transitioned some of our ONR-sponsored multi-frequency technology to NOAA. An 8-frequency sensor is currently moored in the Bering Sea, where it has been reporting volume scattering data via the Iridium system every 20 minutes from a depth of 17 m. The data are being processed to estimate abundances of zooplankton and micronekton for use in trophic models for the area. The Bering Sea supports one of the most economically valuable fisheries in the US EEZ. Estimates are that between 40 and 50% of the fish consumed in the US come from fisheries in that ocean area. The present deployment follows several multi-month deployments on moorings by NOAA in the Coastal Gulf of Alaska in 2002, ‘03 and ‘04. Those data revealed continuing declines in North Pacific zooplankton biomass.

RELATED PROJECTS

We have been supporting NOAA / NMFS / AFSC with sensors and analysis support for a program in which TAPS-8 acoustical zooplankton sensors are being used to measure biomass and size spectra for zooplankton and micronekton in the coastal Gulf of Alaska (2002, 2003 and 2004) and in the Bering Sea (2006). (Napp, *et al*. 2003; Holliday *et al*. 2005; Bond *et al*. 2006). That work is funded under NOAA AB133F05SU3288, but the sensor technology and analysis methods were developed over a period of several years under ONR Contract N00015-00-D-0122 and it’s predecessors. The transition of hardware, its deployment, maintenance and the data analysis to NOAA are essentially complete and we are beginning the process of preparing some publications.

We are using a simple acoustical sensor to examine the effects of epibenthic phytoplankton and benthopelagic zooplankton on acoustical scattering from the seabed. This *ad hoc* project addresses the possibility that oxygen is being generated by photosynthesis of marine algae in the top few mm of a sandy seabed in shallow water and that this might be a source of small gas bubbles, both in the seabed and in thin layers of phytoplankton in the water column. Examining emergence and reentry of zooplankton from the seabed is also a part of this work. All of these processes may impact the thin layers that are our focus for the LOCO project.

We have continued a low level of support, mostly involving acoustical calibration services, for Pete Jumars (TAPS) (Taylor *et al*. 2005; Abello *et al.* 2005) and Mark Benfield (ADCP).

We are in the process of completing our funded research under ONR Contract N00015-00-D-0122 (DO #3). This work is related to the simultaneous use of multiple frequency and multi-static scattering in order to develop some new acoustical tools for use in remotely describing and studying zooplankton and micronekton.

REFERENCES

Abello, H.U., S.M. Shellito, L.H. Taylor, and P.A. Jumars. 2005. Light-cued Emergence and Re-entry Events in a Strongly Tidal Estuary. Estuaries 28(4): 487-499.

Bond, N.A., D.V. Holliday, C.W. Mordy, J.M. Napp and P.J. Stabeno. 2006. Linkages between physical conditions in the coastal Gulf of Alaska and zooplankton biomass and size composition during 2002-04. PICES/GLOBEC Symposium (Poster T2-2684).

Holliday, D.V., J.M. Napp, C. Greenlaw, and P.J. Stabeno. 2005. Interannual Comparisons of Zooplankton Biomass in the Gulf of Alaska Using Bioacoustical Sensors. CGOA GLOBEC PI Meeting, January 2005, Seattle, WA.

Napp, J.M., C.F. Greenlaw, D.V. Holliday, and P.J. Stabeno. 2003. Advection of shelf zooplankton in a predominantly downwelling ecosystem: Bioacoustic detection of the dominant modes of variability. Science for Resource-Dependent Communities, 13 - 17 January 2003, Anchorage, Alaska.

Taylor, L.H., S.M. Shellito, H.U. Abello, and P.A. Jumars. 2005. Tidally Phased Emergence Events in a Strongly Tidal Estuary. Estuaries 28(4): 500-509.

PUBLICATIONS

McManus, M.A., O.M. Cheriton, P.J. Drake, D.V. Holliday, C.D. Storlazzi, C.F. Greenlaw, P.L. Donaghay. 2005. Thin Layers and the Transport and Retention of Marine Plankton. Mar. Ecol. Prog. Ser. 301: 199-215. [published, refereed].

Holliday, D.V. [2006]. Theory of sound scattering from the seabed. Chapter 2 in *ICES Cooperative Research Report on Acoustic Seabed Classification.* [submitted, refereed].